Factors That Influence the Accuracy of Intraoral Scanners

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Intraoral scanners (IOSs) have become increasingly popular in the field of dentistry for capturing accurate digital impressions of patients' teeth and oral structures. The accuracy of intraoral scanning is influenced by various factors such as scanner selection, operator skill, calibration, patient's oral anatomy, ambient conditions, and scanning aids. Maintaining updated software and understanding factors beyond scanner resolution are crucial for optimal accuracy. Conversely, smaller IOS tips, fast scanning speeds, and specific scanning patterns compromise the accuracy and precision. By understanding these factors, dental professionals can make more informed decisions and enhance the accuracy of IOSs, leading to improved final dental restorations.

accuracy digital impressions digital scans

1. Introduction

The most significant evolution in dentistry in recent years is manifested in the emergence of digital dentistry [1]. The seamless integration of advanced digital technologies has revolutionized the landscape of this field, with intraoral scanners (IOSs) emerging as pivotal game-changers. The development of IOSs was driven by the aspirations to improve traditional impression-taking processes, which are frequently subject to human error, with an ultimate goal of rendering them less technique sensitive [2].

The introduction of IOSs has signaled a paradigm shift in the field, offering substantial advantages that span from increased patient comfort to the production of highly accurate dental restorations [1][3]. As a result, these digital technologies have earned profound recognition in the profession, serving as dependable, precision-oriented instruments for recording dental structures.

The accuracy of IOSs is not merely a desirable trait, rather, it is an absolute requisite [2][4]. The precision of these devices critically influences the integrity and fit of final dental restorations, directly impacting their functional performance and esthetic outcome [2][4]. Inaccurate scans can lead to restoration misfit, which may compromise periodontal health, function, and longevity of the restoration, further necessitating revisions and additional clinical sessions [5]. Therefore, assuring IOSs' accuracy should remain paramount to the successful employment of these devices in clinical and laboratory settings.

The accuracy of IOSs has been characterized in the literature by two independent factors: trueness and precision. Trueness refers to the degree of variation between the shape captured by the tested impression method and the

original geometry (as in comparing a reference master cast with the digitized model). In contrast, precision measures the extent of variations or deviations among impressions within a specific test group (as in intragroup comparison of digitized models) [5][6][7].

However, ensuring the accuracy of intraoral scanning is a multi-faceted task, influenced by a variety of factors. These encompass operator-related aspects, such as their skill, experience, and continued training [8]. Furthermore, patient-oriented variables like their cooperation, oral condition, and the nature and location of materials and preparations to be scanned can significantly affect the scanning accuracy [3][6][9][10][11][12][13]. The scanning strategy and environment, inclusive of lighting conditions [1] and chosen scanning protocol [2][14][15][16], also weighs in on the final scanning accuracy. Notably, elements integral to the scanner systems themselves [12][14][17], such as hardware capabilities, software versions [18], and scanning resolution [11], contribute to the overall efficacy of an IOS.

2. Factors Influencing the Accuracy of IOS

2.1. Operator-Related Factors

When exploring IOSs' accuracy, one must acknowledge various factors significantly influenced by operator decisions. These include the operator's proficiency with the device [19], operating distance and angulation [20][21][22], the scanning pattern or sequence [14][15][23][24], and protocols used for establishing cut-off points, re-scanning, and overlap [25][26][27][28][29]. A comprehensive understanding of these crucial influences is central to optimizing the scanning accuracy of IOSs and successfully incorporating these devices into regular dental practice. Dental professionals should appreciate and comprehend these factors fully to maximize the utilization of IOSs [8].

2.1.1. Operator's Proficiency with the IOS

Several studies have demonstrated the impact of operator experience on the accuracy of scans generated by different IOSs. Lim et al. [19] conducted a study to evaluate the impact of dental practitioner's 'experience curve' on the precision and trueness of full-arch scans using two different IOSs, TRIOS (3Shape, Copenhagen, Denmark), and iTero (Align Technology, San Jose, CA, USA). Twenty dental hygienists, grouped based on their years of experience, scanned the assigned patients' oral cavity ten times each. The findings showed that the Trios scanner outperformed the iTero scanner in terms of precision. Yet, the iTero scanner improved in trueness with repeated use, a trend not observed with the Trios. Interestingly, longer clinical experience significantly enhanced the trueness of the iTero scans after multiple uses, especially in the maxillary arch [19].

2.1.2. Scanning Distance and Angulation

Based on the available evidence, it is clear that various scanning parameters, particularly scanning distance and angulation, impact the accuracy of IOSs. The study conducted by Rotar et al. [20] using i700 (Medit, Seoul, Republic of Korea) IOS, showed that a scanning distance of 10 mm presented the highest accuracy; however, they also highlighted that precision decreases as the scanning distance increases [20]. This aligns with findings from Kim et al.'s [21] earlier study using TRIOS 3 (3Shap), CS 3500 (Carestream, Rochester, NY, USA), and PlanScan

(Planmeca, Helsinki, Finland), which indicated peak accuracy at scanning distances of 2.5 mm and 5.0 mm, while a distance of 0 mm was the least accurate [21].

2.1.3. Scanning Sequence

Scanning sequence has an influence on the trueness and precision of IOSs. Studies by Diker et al. [14][23] have revealed the impact of scanning sequence on the trueness and precision of the scan, particularly when scanners like iTero (Align Technology), Virtuo Vivo (Dental Wings, Montreal, QC, Canada), Planmeca Emerald (Planmeca), and Primescan (Dentsply Sirona) are in question. Similarly, Oh et al. [15] reported that different scanning strategies, such as vertical rotation, continuous horizontal, and segmental, can alter scan trueness significantly, though the precision seemed unaffected and scanner type did not appear to influence the outcomes [15].

2.1.4. Cut Out-Rescan and Overlapping Procedures

Rescanning, as a method to acquire data from previously unscanned regions, completes the 3D mesh geometry of scanned surfaces. In particular, it is often recommended in the digital manufacturing workflow for tooth- and implant-supported prostheses to fill scan gaps or ‘mesh holes’. However, the complexities of the rescanning process, such as cutting off and re-acquiring data, or alternatively overlapping new data over pre-existing scans, have shown varied implications on scanning accuracy [25][26].

2.2. Patient-Related Factors

Patient factors refer to the specific intraoral conditions of the patient, which significantly impact the accuracy of IOSs [13]. Such influential factors include characteristics of the scanned area within the oral cavity [10][11][12][17][30][31], tooth preparation design [3][4][6][9][32][33][34][35], restorative materials, surface treatments, and wetness conditions of the digitized surfaces [7][36][37][38][39]. Implant-specific parameters such as interimplant distance, and the position, angulation of existing implants, and scanbodies also influence accuracy of the scans [13][40][41][42].

2.2.1. Characteristics of the Scanned Area

Location of the Scanned Area

Numerous studies have evaluated how the accuracy of resulting scans is influenced by the location of the scanned area. An experimental study by Treesh et al. [10] evaluated the accuracy of four distinct IOSs, namely the CEREC Bluecam (Dentsply Sirona), CEREC Omnicam (Dentsply Sirona), TRIOS Color (3Shap), and CS 3500 (Carestream). They reported that the accuracy of scans is significantly influenced by the location of the scanned area. Benchmarked against a precisely 3D-printed reference cast, all IOSs consistently underestimated the dimensions of the reference file, affecting the trueness of the scans. This underestimation became more prominent within the posterior regions of the dental arch, where the local errors stretched beyond 100 µm for every scanner analyzed [10].

Extension of the Scanned Area

A systematic review by Abduo et al. [30] based on 32 included studies examined the accuracy of various IOSs for dental impressions, analyzing factors influencing their performance. Full-arch scanning showed a potential for more deviations compared to partial-arch scanning [30].

Arch Width

A study by Kaewbuasa et al. [31] compared the accuracy of three different IOSs: TRIOS 3 (3Shape), True Definition (3M ESPE), and Dental Wings (Dental Wings Inc.), considering varying dental arch widths. The accuracy, denoted in terms of trueness, differed significantly across these systems. Dental Wings (Dental Wings INC) registered significant relative length and angular deviations in smaller to medium-sized dental arches when compared with the TRIOS 3 (3Shape) and True Definition (3M ESPE) scanners. However, it showed enhanced accuracy when used with larger dental arches. On the other hand, True Definition has shown a tendency to cause inaccuracies when used on larger arches. TRIOS 3 (3Shape) consistently maintained its trueness across dental arches of all sizes, indicating its robustness towards size variations. This highlights that the accuracy of full-arch scans produced by certain IOSs may indeed be affected by the dimension of the dental arch being scanned. It is important to note that larger dental arches necessitate a greater scanning area than their smaller counterparts, which makes it impossible for an IOS to capture the entire arch in one go. Hence, multiple overlapping scans are performed and amalgamated utilizing stitching algorithms, which could introduce additional discrepancies [31].

2.2.2. Tooth Preparation Design

Extensive research has emphasized the impact of preparation design on IOS accuracy, including aspects like the preparation type, finish line placement, tooth geometry, complexity, and finishing procedures [4][6][9][32][33][35].

Ashraf et al. [6] reported that for improved scan trueness, extracoronal preparations were favored over intracoronal ones, suggesting that preparation design plays a significant role. Additionally, subtle changes in tooth geometry such as increased convergence or divergence between opposing walls can improve trueness. The finding was explained by the preparations made with more straight, vertical walls being more prone to errors caused by camera misalignment, emphasizing the complex relationship between tooth geometry and scanning accuracy.

2.2.3. Restorative Materials, Surface Treatments and Wetness Conditions

Revilla-León et al. [36] analyzed the impact of restorative dental materials and their specific surface treatments on the scanning accuracy of IOSs. Their findings uncovered considerable discrepancies in scanning accuracy across different materials. Restorative materials, such as conventional and milled Polymethyl Methacrylate (PMMA) and additively manufactured bis-acryl-based polymer, attained the highest scanning accuracy when they were polished. Conversely, high noble alloy specimens had the lowest trueness values. While glazed zirconia crowns had comparable trueness values to their polished counterparts, a polished surface in other materials resulted in better trueness than a glazed one. Precision was lowest in the conventional PMMA when it was glazed and highest in the polished bis-acryl composite resin. The findings suggest that both the type of restorative material and its surface treatment significantly influence the scanning accuracy of IOSs [36].

The study by Agustín-Panadero et al. [38] extended this exploration by investigating the impact of different restorative materials and varying levels of surface wetness on the accuracy of IOSs. The research used four groups identified by the first molar's material: natural tooth, zirconia, lithium disilicate, and nanoceramic resin crown, further subdivided into dry, low-, mild-, and high-wetness categories. The TRIOS 3 (3Shape) IOS was utilized for all scans. Findings indicated that both the restorative material and surface wetness significantly affected scanning trueness and precision. Greater wetness levels resulted in lower trueness and precision, with dry and low wetness subgroups outperforming mild and high wetness counterparts. In terms of material impact, natural tooth, zirconia, and lithium disilicate exhibited superior trueness under dry and low wetness conditions compared to the nanoceramic resin crown group, although no significant precision difference was found across all materials. Under high wetness conditions, lithium disilicate demonstrated superior trueness and precision. These results suggest that drier surfaces are recommended to enhance scanning accuracy, and both the presence of saliva and the type of dental restorations may reduce the IOS's performance [38].

2.2.4. Implants and Scanbodies

A study by Thanasrisuebwong et al. [40] assessed the impact of inter-implant distances on the accuracy of IOSs. Three models with different distances between two scan bodies were fabricated and then scanned using two IOSs. The results showed that inter-implant distance had a significant effect on both scanners. Trueness and precision decreased with longer inter-implant distances, but the distortions were not clinically significant [40]. A study by Gómez-Polo [41] examined how scan body geometry, bevel location, implant angulation, and position affect the accuracy of full-arch implant scans. Two definitive casts with implant analogs were used, and various subgroups based on bevel position were created. The results showed that bevel position and inter-implant distance affected linear discrepancies. Lingual orientation and parallel implant analog positions yielded better accuracy. Implants positioned where scanning finished had higher distortion compared to contralateral implants [41].

2.3. IOS-Related Factors

Available literature discuss various IOS-related factors that can impact the accuracy of scans. It provides insights into the influence of ambient lighting and temperature on scanning accuracy [43][44][45][46][47], as well as the importance of surface pre-treatment [48] and scan resolution [11][49]. The software versions and updates of the scanners are also highlighted [18][50], along with the impact of scanner head size on trueness and precision [51][52]. These findings emphasize the need to optimize scanning conditions and consider multiple factors when aiming for optimal accuracy in dental scanning processes.

2.3.1. Scanning Environment

Ambient Lighting

Ambient lighting conditions can influence the accuracy (precision and trueness) of IOSs, but the ideal conditions vary depending on the selected IOS. In a study conducted by Revilla-Leon et al. [43], they reported that different lighting conditions yielded better results for different scanners. For the iTero Element (Align Technology), improved

accuracy was observed under chair and room light conditions. For the CEREC Omnicam (Densply Sirona), optimal accuracy was attained under zero light conditions. Meanwhile, the TRIOS 3 (3shape) scanner exhibited superior accuracy under standard room light conditions [43].

Ambient Temperature

Ambient temperature changes had a detrimental effect on the accuracy (trueness and precision) of the IOS tested in a study conducted by Revilla-leon et al. [47]. A full-arch maxillary dentate Type IV stone cast was digitized using an industrial scanner and a TRIOS 4 (3shape) IOS under different ambient temperature conditions and four groups were created based on temperature changes. The results showed that ambient temperature changes had a negative impact on the trueness and precision of the IOS. Increasing the ambient temperature had a greater influence on the scanning accuracy compared to decreasing the temperature. Thus, maintaining a stable ambient temperature is crucial for achieving accurate intraoral scans [47].

2.3.2. Surface Pre-Treatment

A study conducted by Oh et al. [48] investigated the effect of scanning-aid materials on the accuracy and efficiency of full-arch scanning using IOSs. They used two types of scanning-aid materials for their experiments: IP Scan Spray (IP-Division, Haimhausen, Germany) and Vita Powder Scan Spray (Vita Zahnfabrik, Stuttgart, Germany). These were compared to a control group that had no treatment. The findings from the study showed that, statistically, there was a significant improvement in the precision of the scanned images when scanning-aid materials were used, compared to those from the no-treatment group. However, there was no difference observed between the trueness and the types of scanning-aid materials used.

2.3.3. Scan Resolution

A study conducted by Medina-Sotomayor et al. [49] provides insights into the resolution and accuracy of various IOSs used in digital dental impressions. According to their findings, CEREC Omnicam (Densply Sirona) demonstrated the highest resolution among the scanners tested, followed by True Definition (3M ESPE), TRIOS (3shape) and iTero (Align Technology). The study did not find a significant relationship between resolution and accuracy of the IOS, except for CEREC Omnicam (Densply Sirona) and its precision. This study concluded that resolution has no direct correlation with the accuracy of capturing a full-arch scan. It suggests that other factors beyond resolution alone, such as software algorithms, scanning technique, and material properties, may influence the overall accuracy of digital impressions [49].

2.3.4. Software Versions and Updates

The impact of different software versions on the accuracy of the same IOS was studied by several research groups. By studying the CEREC Omnicam (Densply Sirona) with software versions 4.4.0 and 4.4.4, Haddadi et al. [50] reported that software version can significantly affect the accuracy of an IOS. They concluded that it is important for researchers to include the software version of scanners when publishing their findings. This

information allows other researchers and practitioners to replicate the study accurately and understand the potential variations in results due to different software versions [50].

2.3.5. Scanner Head Size

In a study by Hayama et al. [51] comparing digital and conventional impressions for removable partial denture fabrication, researchers used mandibular Kennedy Class I and III models with soft silicone simulated-mucosa on edentulous ridges. Digital impressions obtained with IOSs had superior trueness but inferior precision compared to conventional impressions. The larger scanning head of the IOS showed better trueness and precision and required fewer scanned images. Overall, digital impressions showed promise but still had some areas for improvement when compared to conventional impressions for accuracy in removable partial denture fabrication [51].

3. Conclusions

Ensuring the accuracy of IOSs is a multifaceted task that involves various factors. These include operator-related, patient-related, and IOS-related variables. The accuracy of IOSs is significantly influenced by several critical factors, including the choice of scanner, operator's expertise, calibration of scanning parameters, and unique aspects of the oral anatomy. Rescanning procedures can reduce the overall scanning accuracy, necessitating adherence to manufacturers' guidelines. While IOSs may show promise in partial-arch impressions, complete-arch impressions remain challenging due to larger arch sizes needing multiple overlapping scans, potentially leading to additional discrepancies. Factors like ambient lighting and temperature also substantially affect accuracy and scanning time, although not uniformly across devices. The utilization of scanning-aid agents can reduce working time; however, their effect on trueness was not consistently significant. The results also imply that higher resolution does not guarantee more accurate full-arch scans, suggesting the need for a comprehensive understanding of parameters like software algorithms, scanning techniques, and material properties. Importantly, keeping the software updated can help achieve optimal performance. Contrarily, smaller tips, fast scanning speeds, and certain scanning patterns can negatively influence accuracy and precision. By understanding and addressing these factors, dental professionals can enhance the accuracy of IOSs, leading to improved clinical outcomes, reduced restoration misfit, and increased patient satisfaction.

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